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Metamorphosis of Media in the Life of Audio Documents: Preservation, Restoration, and Critical Editing of Twentieth-Century Western Art Music

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ABSTRACT: The preservation, restoration, and critical editing of musical works from the Western art tradition composed entirely or partially on audio media poses significant challenges for music scholars, editors, engineers, and archivists. These include understanding the various technologies composers have used in their work, making sense of the array of audio tools and media available today to restore and reissue electronic music, and confronting the underlying theoretical and philosophical issues that such projects necessarily entail. Focusing on the work of scholars based in North America and Western Europe, this article will discuss English, French, and Italian language literatures in musicology, philology, literary criticism, and philosophy, as well as work in engineering, information theory, and theories of communication systems, to reflect on the nature of electronic music compositions and the metamorphoses that such compositions undergo in the process of their transmission through various kinds of media. After discussing a number of recent editing and restoration projects, the article argues that the transmission of audio documents depends on the "diasystemic" interaction of a work's original media and the new media into which it is transferred. It suggests that attempts to identify and preserve audio documents according to a "best copy" standard denies both the historicity of musical production and our knowledge about it, and that recorded musical works are inseparable from their media transformations.

KEYWORDS: Audio Documents, Twentieth-Century Music, Electronic Music, Preservation, Restoration, Critical Editing

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INTRODUCTION

This article addresses the problems involved in the preservation of musical works from the Western art tradition composed entirely or partially on audio media, including both electronic music and "mixed music" (music with both acoustic and electronic components). Scholars engaged in this endeavor must consider a range of topics, including the various means of production used by composers to create the music, issues of technological obsolescence, and the media forms that are employed to reproduce and reissue the music today. This requires the co-participation of those from a number of disciplines, both ones of a historical-critical nature (including music analysis) and ones of a technological nature (including audio signal analysis, processing, and information retrieval; information theory; and theories of communication systems). Such work must come to understand the nature of electronic musical compositions and the metamorphoses that they have undergone in the process of their transmission through differing media. Focusing on publications by scholars based in North America and Western Europe, the article will review the English-, French-, and Italian-language literatures in these disciplines, including writings from musicology, philology, and philosophy, to illustrate the range of ways that contemporary researchers have come to understand the preservation of electronic music in the Western art tradition.

BACKGROUND

During the twentieth century, forms of technological orality arising from the broad diffusion of radio and television (Ong 1967) have informed the way composers, musicians, and listeners perceive sound and voice. Here, the order of the sensible has been altered by an expanded organology resulting from the vast proliferation of devices for creating and modifying musical sound. In the 1960s and 1970s, the invention of electronic instruments introduced disruptive innovations; audio and video recording instruments allowed humans to perceive previously undetectable events, and the implementation of techniques for the micro-temporal analysis of the audio signal led to a change in the scale of observation of sound phenomena. As early as the 1950s, new technology allowed a generation of composers to observe the waveforms and the spectral content of sounds and voices at different scales. Sonic processes that involve the integration of timbre and pitch were brought to light, as was the timbral relevance of transients in the sound of acoustic instruments and the inseparability of sound from the noises inherent in a given medium. As sound production methods change, so does compositional thought, and composers experimented with semiography, sometimes to bizarre extremes (think, for instance, of the work of Sylvano Bussotti), in an effort to transcribe the intrinsic properties of sound inexpressible by traditional notation. But perhaps the most important facet of this media revolution was the rapid technological obsolescence of instruments and recording systems. This new sound world seems to lack the possibility of a specific historicity—that is, it did not appear to have the means to make itself accessible to those in the future. This is in stark contrast to the classical world of acoustic music and its instruments, where scholars could draw on historical records to understand the past and where technological changes emerged more slowly. These media transformations have changed the nature of musical heritage in the Western art tradition, which—in addition to using long-standing media (e.g., parchment, paper, or cardboard) and acoustic instruments—now covers a multitude of electroacoustic, electronic, and computerized instruments and a myriad of new analog and digital recording media, all of which are bound to rapid and continuous technological obsolescence (Vidolin 1995). This revolution has sparked discussions of a wide range of philosophical, technological, practical, historical, and critical issues (Orcalli 2001; Lysloff and Gay 2003; Sterne 2003, 2012; Bayley 2010; Bonnet 2012; Gayou 2013; Frange and Lacombe 2014; Arbo and Lephay 2017).

Composers today are able to work with a variety of writing and recording methods and forms (records, tapes, computers, and the many other kinds of media that have followed over time). They move with ease between traditional notation systems and systems that synthesize sound in real time, such as live electronics. The shift from traditional notation to a more systemic concept of writing and sound production, with greater attention to the performative dynamics of musical processes, signals deep changes in the definition of music composition. Discrete notational systems are giving way to continuous sound representation systems, where the border between sketch and score remains fuzzy. As philosopher Nelson Goodman (1984) has noted, on the one hand, "an extreme spirit of *laissez faire* has led some composers to use systems that restrict only slightly the performer's freedom to play what and as he pleases," but "such latitude is not incompatible with notationality.... At the opposite extreme, some composers of electronic music, with continuous sound-sources and means of activation, and with the human performer dispensable in favor of mechanical devices, seek to eliminate all latitude in performance and achieve 'exact' control." Electronic writing would thus be considered "autographic" (190–191). This conception of composition identifies the work with its technological instantiation of the moment, without conceiving its future evolution. Goodman does not consider that even though the electronic music composer intends to autographically fix the first "instance" of the work on an audio record, its autographic character is weakened because its fruition is linked to the reproduction systems it uses, to their technological development over time, and to the transfer of audio tracks onto other supports in different technological and cultural settings. In this context, we cannot forget that the sound system that

the composer uses to produce the work is integrated into the work itself; it is part of the compositional project (Vidolin 2013), and it defines the possible conditions of its form and content.

In the second half of the twentieth century, scholars such as the philosophers Harold Adams Innis (1952), Eric Havelock (1963), Marshall McLuhan (1964), and Walter Ong (1967) began to reflect on media and their social impact. In the field of music, composer Pierre Schaeffer, one of the great forerunners of electronic music, moved beyond the sociological dimensions of these reflections to highlight two aspects of communication that came to the fore during World War II: the scientific exploration of communication systems and the social contextualization of the various artistic and scientific factors implicit in the new means available. Schaeffer (1970) states that these phenomena arose "because *diffusion* (which, from the outset, was the very mission of radio and television, and justified its existence) only gradually became a completely different reality: a social phenomenon, now capable of exerting a *feedback effect* on the message" (27).[1] The model proposed by Schaeffer brings mathematician Claude Shannon's (1949) theory of information into the world of artistic production. Here, the sender has a double role: they are both an artist (engaging in expression) and a producer (engaging in production; Cossettini and Orcalli 2019). Rooted in this perspective, which centers on production systems, publishing and sound recording are, according to the musicologist James Grier (1996), on the same level; in fact, he argues that "the [musical] work exists in a potentially infinite number of states, whether in writing (the score) or in sound (performance); the text is one of those states" (23).

It is almost proverbial to say that the advent of a new medium highlights the limitations of the previous ones. Reflections on media transitions, even the most recent ones, therefore constitute the first element of inquiry into changes in habitus, the set of taken-for-granted practices that constitute a social world. Such methodological reflections, which we will pursue below, must be carried out if one is to approach the topic of the preservation and restoration of recorded music with a spirit as free as possible from intellectual models that confuse the things of logic with the not infrequently "unreasonable" but real conditions of the logic of things.

In his masterful review of mass media, which centers on the polarity of the notions of *trace* and *aura*, cultural critic Walter Benjamin (1936) provided a clear analysis of the sensorial and experiential forms of expression deriving from the complex of technical-theoretical conditions created by audiovisual production in its infancy. Benjamin could not have imagined that, from the moment a distance or gap—that is, a kind of discontinuity—was created in the media sphere between the analog and digital, a time would eventually come when the forms of artistic production of his time would be reaffirmed through an act of recognition of the artistic and documentary value of historical recordings. From the moment that the new digital media system started to administer to the whole analog experience the narcotic of faithfully rendered signals through digital encoding, the meeting of the two systems produced an *aura* that had been unknown until then, and this is a result of the technical-theoretical distance that separates these media spheres. Extending Cesare Segre's (1981) notion of "diasystems" (discussed further below), we suggest that the resulting diasystemic tension between analog and digital systems, which arises when media of the former kind is reproduced through the latter kind, raises questions about authenticity and value in art music: in digital reissues of analog works, conceptions of a reissue as "authentic" depend on both the gap between the two kinds of media and the recognition of the distance between the analog source and the digital reissue. This is the condition of possibility for any editing of audiovisual sources (Canosa 2001) that seeks to counteract the a-critical and sometimes fraudulent replacement which the new media system often involves.

Today, on the Web, musical works are separated from their history: losing the technological-cultural references to the laboratories and production centers where they were born, those works are condemned to a kind of anonymity and to the fate of being endlessly recomposed in the name of the impossibility of fixing meaning, of enclosing them within final representations. In this way, plagiarism loses its pregnancy: every repetition, every reissue, is at the same time a change, a reinvention of semantic content. Each production that can be easily communicated moves through a network of signs, a multiplicity of voices proliferating through intersubjective experiences. In this context, the idea of copyright is jeopardized because any claim to originality and authenticity

is denied. In separating history (the conditions under which a work was produced) from the documents produced at any given moment (in this context, musical works produced under a set of conditions), a work mediated by the Web is witness to nothing else but its own existence; it refers to nothing but itself.

ARCHIVES, LIBRARIES, AND AUDIO DOCUMENTS

For more than a century, music archives and libraries have stored not only books, manuscripts, or silent scores but also audio documents. Regardless of whether they are music performances, electronic artworks, popular music, or recordings of life experiences, these audio documents, archived as acoustic phenomena, are beginning to eclipse the centuries-old predominance of primarily visual texts, ones that were meant to be seen, not heard. Furthermore, the birth and diffusion of home recording equipment has led to the creation of sound documents (home video and audio recordings operating as sound journals) intended for private use, which often—especially if they bear witness to a wider cultural context—have become part of collections available to the general public.

It is possible to make a distinction between at least two types of audio documents: recordings of acoustic events, on the one hand, and musical works that were designed—or performed—to be recorded, on the other (Arbo 2017). The latter of the two types of audio documents are the result of audio signal processing and control activities: an editing process by which the composer fixes heterogeneous audio materials using a writing form (the recording media itself) that is neither visible nor directly legible and can only be heard through an interface device. Here, composing and recording cannot be separated, and they involve not only the composer but also the specific technology the composer used, the sound engineers in the studio, and their relations with any performers. On the border between these two types of audio documents are the tapes used by composers to record audio "notes," composition experiments, preparatory materials that are later processed to produce final "drafts" of an electronic work, copies of electronic parts (for studying or rehearsing), and so forth. Today, these documents are kept in archives and are fundamental to studying the genesis and development of works of electronic music, as are the written drafts and sketches found in the composers' personal papers. And although many scholars have discussed written drafts and sketches (see, for example, Kerman 1995; Decroupet and Ungeheuer 1998; Borio 1999; Hall and Sallis 2005), there is no body of work on the unique features of preparatory audio materials.

Scholars have, however, raised questions about the ontological status of sound documents and the relationships among works, scores, performances, and recordings.[2] Musicologist Peter Kivy, for instance, observes that sound syntheses of notated music (which are also to be understood to include scores of classical music) hardly fall within the opposition between type and token, as enunciated by philosopher Charles Sanders Peirce (Kivy 2002, 217). In Roger Pouivet's (2014) ontology of music, there is a clear distinction between the recording of an event and a work of recorded music, while musicologist Stephan Cottrell (2010) argues that there is a continuum between the two poles. These reflections reveal a more general need for the study and management of knowledge-bearing artifacts.[3] In the last years of the twentieth century, the popularity of relational databases for managing catalogs of musical artifacts—first offline and then transferred, often uncritically, to the world of the Web—caused the resurgence of ontologies of music that took the form of taxonomical categorization (Smith 2008). The tremendous work of digitizing music catalogs has thus reopened the age-old rift between an archival perspective, oriented toward the description of an individual artifact according to its unique and defining characteristics, and a "catalographic" approach, which necessarily tends toward the standardization of classes (Riva, Le Bœuf, and Žumer 2017). When the standardization of electronic art music is carried out in an uncritical manner, which often happens in documentary work or in the publishing industry, we may fail to recognize that the sound document and its distinctive form is often constitutive of the musical work itself. To lose sight of these distinctions, which form the descriptive basis of sound documents, would be to deflect all subsequent processes of preservation and restoration (Arbo 2018) and, consequently, in our case, to distort the canons of twentieth-century electronic music.

The issue of description does not only impact institutional archives because, in this era in which the Web has demonstrated its archival potential, more and more composers make use of sound samples, melody databases, and digital library repositories. The use of such sources is not limited to popular music (Dannenberg et al. 2014; Delfino 2017); increasingly, they are also being used in "academic" composition. Authors today can access and contribute to a universe of audio materials, procedures, and languages, where historicity and innovation coexist in a kind of eternal present. Contemporary scholars are thus faced with a complex set of documents and need to reconsider the older analytic models they have used, which are often based on text abstraction: such painstaking work must start by recognizing the historical value of the sound documents and by developing new cataloging, information management, restoration, and presentation systems. Such work will allow our musical heritage to be more accessible to the general public.

In 1961, journalist, producer, and theorist Jean Thévenot wrote: "Developments in sound recording are now such that no specialist, it would seem, and *a fortiori* no layman, would be in a position to make an exhaustive inventory of the world's sound archives, all the more so as, at the same time, they are still a matter for pioneers" (1184).[4] Thanks to Thévenot, scholars in the years that followed began to study the difficulties involved in managing archived audio documents. How could the tension between the physical preservation of an item and access to its content be reconciled in the world of audio? Existing methods for managing audio documents, developed with regard to physical copies of texts and museum artifacts, could not be simply applied to audio recordings; they needed to be reviewed completely.

A BRIEF HISTORY OF AUDIO RESTORATION AND ITS THEORETICAL FOUNDATIONS: INFORMATION THEORY, SOURCE CRITICISM, AND DIGITAL SOUND PROCESSING

Art historians were the first scholars to address the topic of the restoration of cultural works. The idea that the artist's intention is a key principle in restoration emerges, for instance, from the writings of the restorer Helmut Ruhemann (1968), who stated, "We must try to recover as far as possible the original appearance of a painting where it is obscured. Here the intention of the artist is the guiding standard" (148). For Ruhemann, the restorer applied this standard not with reference to a painting's history but by relying on a series of technological controls and operations. Art historian Cesare Brandi (1963), however, offered a different perspective. Focused especially on the field of painting, he noted that "neither a preserver nor a restorer can make such a claim [about the artist's intention], precisely because it is a claim, an indemonstrable claim, to be able to go back to a supposedly original appearance of which the only valid testimony would be the work when it was completed (i.e. without the passage of time), which is a historical absurdity" (101).[5] The crucial point of contention here was the removal of a work's patina, which, according to Brandi, was an integral part of the history of a painting.

Animated by the spirit of visual art restoration guidelines from earlier in the twentieth century (such as ones developed in Athens in 1931; Italy in 1932 and later in 1972; Venice in 1964; Amsterdam in 1975; and Washington, DC, in 1987), UNESCO in 1991 published a guide to the preservation of audiovisual documents, which both established international professional standards for the preservation, restoration, and reissuing of analog audio and video recordings and defined an ethics for audiovisual documentary preservation. In particular, the audio section of the *Guide to the Basic Technical Equipment Required by Audio, Film and Television Archives* (Boston 1991) addressed the obsolescence of large archival collections of records, tape recordings of folklore events, radio and television recordings, and video recordings of plays and festivals. The *Guide*'s approach to active preservation can be summed up in the following way: *the function of the archivist is to save, not to rewrite, history*. In this context, preservation therefore meant (a) ensuring the recovery of the recorded signal, while respecting the characteristics of the original format; (b) ensuring the faithful transfer of the signal to digital media; and (c) not arbitrarily exposing the documents to modern audio processing techniques.

The authors of the *Guide* did not go into questions about the intrinsic value of individual recordings but instead focused on defining a basic standard for preservation, irrespective of the characteristic properties of the documentary content. Significantly, the *Guide* does not offer specific instructions for the safeguarding and restoration of works of art music recorded on tape. The instructions in the *Guide* were driven, on the one hand, by the urgent need to save a heritage of endless hours of recording and, on the other, by an awareness that the resources made available for this undertaking by institutions would be limited. The *Guide* thus bears witness to the gradual emancipation of audio documents as independent sources; it focuses on the cultural relevance of audiovisual documents for oral traditions and shows renewed sensitivity to a documentary heritage that was generally regarded by historians as insignificant.

Engineers William Storm (1980, 1983) and Dietrich Schüller (1991, 1994, 2001), who made an important contribution to the *Guide*, led debates about the applicability of preservation models and terminologies developed by other disciplines for work on Western art music. Expressions such as "historically faithful copy," as opposed to "reproduction of the true voice of the performer," might sound naive today, but they reveal the complexity of the issues raised in debates about the preservation of sound recordings. Giving a technical definition of "sound fidelity" was no easy task then, nor is it today.

The juxtaposition between an original, live sound and a faithful, recorded copy served the interests of the recording industry right from the outset, as companies sold consumers on the fidelity of their products. In its advertising for a 1902 recording by Geraldine Farrar, for instance, the Victor Talking Machine Company asked, "Which is which? You think you can tell the difference between hearing grand-opera artists sing [live] and hearing their beautiful voices on the *Victor*. But can you?" (1908 Victor Talking Machine advertisement, qtd. in Sterne 2003, 217). Similar claims appeared in adverts for recordings by the tenor Enrico Caruso (Sterne 2003). Like high fidelity, however, the "reproduction of the true voice of a performer" is a myth, one that subsequent trends in sound recording would reveal.

The first of these trends expressed the "positivist" ideal of a technically optimized image, which affirmed what we might call the "truthfulness of nature." In other words, in the age of "preserved" music and of the "reportage" of theater and concert performances, phonographic realism was based on a sort of sufficient persuasion agreement: here, one recognizes that there is a difference between the original live sound and the faithful recorded copy, but this difference is so imperceptible that the listener is sufficiently persuaded otherwise. Here, distortions are considered to be acceptable, and "fidelity" is seen as the absence of patently perceivable infidelities. To achieve this end, sound engineers and producers used specific strategies—such as the selection of performers and the transformations of acoustic instruments depending on the capacities of the phonograph and the microphone being used to record them—to achieve a realistic effect, and these practices go back to the earliest days of recording (Sarnette 1934). The second trend, which developed in the 1960s and 1970s, might be called "illusionist." Here, the record industry pursued the ideal of an "artificial nature," a *rendu intensifié* (Kalteneker 2014); its aim was to stereophonically render an ideal performance in an ideal space. Fidelity was thus no longer about the opposition of original sound and copy; in fact, the original sound itself was a technological outcome of reproduction, with the technology itself defining the horizon of possibilities. In a third trend, which in certain respects was antagonistic to both realism and illusionism, audio signal recording was construed as an independent creative act: recorded products were thus not only about realistically capturing a performance, and the live concert was no longer the sole point of reference for authenticity. These trends in audio recording illustrate a movement toward the full independence of the medium, which affirms itself as a document of a musical *composition*. Here, the composer's action is affected by the machinery that they use. The outcome of its musical production, the magnetic tape with a recording of the electronic part of a composition, is filed with the publisher and distributed for reproduction in concert. This process has resulted not only in copies but also in re-mediation processes (e.g., from tape to record), restorations, and most notably, authorial *variants*. This has occurred both in pop music and in electronic and mixed musical experimentation (Bonardi et al. 2017).

In the 1980s and 1990s, signal processing technology, as well as the theories related to it, was already formidable, having been developed mainly from military uses during World War II (e.g., Kolmogorov 1939, 1941 [1977]; Wiener 1949). This technology had been widely developed by aerospace research, a result of the race to conquer space during the Cold War (e.g., Kalman 1960). *Spectrum estimation* (the analysis of the frequency content of a signal; see Sorenson 1970; Robinson 1982), for instance, has been pivotal for acoustic physics, electronics, information theory, and the development of control systems. In the 1960s, it reached its peak using electronic processors. The impact of information theory on thinking about the restoration of audio documents naturally led scholars to reflect on the ways that the carriers for sound, and audiovisual recording in general, are transmission channels over both time and space. The signal was thus perceived as a message that corresponded to the true sound of the source (the voice of the performer, the sounds of instruments, etc.), which was also inevitably contaminated by the noise introduced in the transmission process in real- or deferred-time. The audio track is represented as the sum of the original unknown signal and of a noise component produced both during the recording and in the reproduction phase. It is thus one of the possible realizations of an aleatory process. In this way, from the point of view of audio restoration, the contours of a specific type of signal degradation were outlined. This signal degradation could come from many sources (acoustic, electromagnetic, environmental, etc.) but, nevertheless, could be divided into two types:

1. disturbances of a local type (i.e., impulsive ones) that affect only part of the signal (e.g., perceivable clicks in records) and are identifiable as discontinuities in the waveform; and
2. disturbances of a global kind that affect the whole signal. These include, most notably, background noise, *wow and flutter*, and some nonlinear distortions.

Many today believe that only digital techniques can be used to restore sound recordings, but we want to emphasize here that there is a long history of analog audio restoration. For example, radio centers throughout the world manually edited magnetic tapes by literally cutting from the tape localized disturbances and flaws, and signal equalization was used to reduce degradations of a global kind (*hiss* or harmonic distortion). High-pass filters were also used to detect impulsive disturbances with a recording's spectral content, located mainly at high frequencies; a low-pass filter was then used to remove the disturbances.

In the 1980s, these analog techniques for restoring sound recordings gave way to the use of digital signal processor (DSP) microchips, which had become sufficiently powerful to handle the complex processing operations required for sound restoration in real-time, or close to real-time. This led to the first commercially available digital restoration systems, with companies such as CEDAR Audio Ltd. in the UK and Sonic Solutions in the US selling dedicated systems worldwide to recording studios, broadcasting companies, media archives, and film studios. Engineers Simon J. Godsill and Peter J. W. Rayner (1998) outlined the reasons that led them to apply signal processing to audio restoration. The introduction of high-quality digital audio media, such as the compact disc (CD) or digital audio tape (DAT), dramatically raised the general awareness and expectations about sound quality, in all types of recordings. This, combined with an upsurge of interest in historical and nostalgic material, has led to a growing demand for the restoration of degraded sources, ranging from the earliest recordings made on wax cylinders in the nineteenth century to disc recordings (78 rpm records, LPs, etc.) and magnetic tape-recording technology, which has been available since the 1950s. In the 1960s, scientists and engineers Thomas G. Stockham, Thomas M. Cannon, and Robert B. Ingebretsen (1975) attempted to avoid the problem of the variability of recording systems by proposing a deconvolution technique to restore the existing sound and account for the distortions of horn-diaphragm recording systems. According to the authors, the analysis of sample acoustic recordings showed that the sound engineers of the time were able to reduce the distortions of the recording system to a minimum. Following this work, classical techniques of filtering and deconvolution have been implemented using DSP technology (Vaseghi 2002). As a result of this, the field of audio signal restoration

benefited from the impressive developments of digital processing techniques. In their wake, the record industry launched publishing projects aimed at retrieving historical editions and focused on the development of new algorithms for restoration (Canazza et al. 2001).

Despite the advances in this area, scholars such as George Brock-Nannestad (1997, 2001) have become skeptical of the utility of software-based noise removal techniques. This is because aggressive noise reduction interventions also attenuate, or in some cases erase, auxiliary signals that are typical of production systems of the time, thus removing information about the technical operating conditions of the original recordings. This is particularly important in terms of preservation. Schüller (1994) has noted that while print technology offers a representation of human thought via a system of symbols that contain a certain intrinsic redundancy, an audiovisual document, by contrast, is an analog representation of a state or physical event: every part of the document, even the noise, contains information spread by the carrier. It follows that any loss of information caused by a degradation of the signal is not retrievable through the structure of its code. When a contemporary engineer "corrects" errors in a recording, listeners lose basic information about the kind of recording technology that was used to produce it. Knowing the technical origin of a musical document and of its recorded track allows for a comparative study of the ways that recordings alter the work, and this cannot be known *a priori*. In this context, any so-called error—that is, any deviation from what is taken to be the source signal, which is the key factor in philological reconstructions—is reduced to mere transmission *noise*.

The clear separation between signal and noise assumed in software-based noise removal, and the very possibility, *a priori*, of the attenuation or even deletion of the latter as an unwanted error, can be understood with reference to what are referred to as "estimation problems," which work from the known to the unknown by way of prediction, filtering, and interpolation. Using terminology he likely inherited from linguistics and philology, mathematician and information theorist Norbert Wiener—in an essay written with Pesi Masani (Wiener and Masani 1957, 1958)—introduced the word "innovation" to indicate a prediction error at a given moment t. This variable includes all new information added by the t^{th} observation measurement of the signal, when previous data are already available. Even though the word "innovation" might sound picturesque in this context, Wiener's mathematical approach has affinities with the methodology used in the textual criticism of philologist Karl Lachmann: the goal in these two approaches is to return a *single* message by projecting information that is derived from data found in sources in a single (synchronic) space; this could, in theory, contain the whole (diachronic) process that informs the innovation. In textual criticism, the transmission of the text (i.e., the signal) to the modern reader passes not through a simple and direct channel but rather through a system of multiple transmitters. In Wiener's model, the transmission itself is the history of the signal, including all innovations. The goal shared by both Wiener and Lachmann is thus to produce a new text (i.e., message) by gradually estimating (predicting) its content and combining (interpolating) the outcomes of the effect of the transmission channels (which, in textual criticism, would be understood as the text's "tradition") and establishing their correlation with the estimate. This would create a "filtering" system (which would be called an *emendatio* in textual criticism) that minimizes innovation errors. In textual criticism, "manuscripts" refer to both source signals and innovations; in this context, the differing distribution of innovations might reveal, and also serve as a guide for, text editing. It is therefore essential, we would suggest, to distinguish between *errors* and *variants*.

Philologist Aurelio Roncaglia (1978) borrowed from information theory in coining the concept of a "text-message" (81). Considering documents as sources of information, philology aims to eliminate as far as possible all distortions that a text-message may have undergone during its transmission—that is, eliminating or reducing "noise"—and ensuring the greatest possible conformity of reception to emission. However, the information theory model does not account for many of the phenomena that textual critics wish to understand. For example, the transmission of the text passes not through a simple and direct channel but rather a system of connections of multiple repeater stations, involving human and interpretive aspects, and is each time recontextualized historically and technologically. The alterations to which the text is subjected thus widen from "mechanical noise" (i.e.,

errors) to a more insidious "semantic noise," up to interferences, superimpositions, or insertions of new signals, all of which are capable of radically transforming the original message. With this in mind, we argue that a combination of historical-critical approaches and technological ones are necessary to understand the transmission of cultural works, and this is particularly important for understanding recorded music. As we argue below, such perspectives are essential for work in audio restoration and the production of critical editions of electronic music.

In the history of audio restoration, there has been a tendency to restrict the study of the sound content of a historical recording to the analysis of its digitized signal (Cappé 1993). When carried to extremes, this approach can lead to significant problems, even in the restricted area of the development of software algorithms, since it reduces the range of knowledge used in modeling signal alterations and gives up a wealth of information useful for developing a model of the original sound. Concerned only with manipulating the digitized information, contemporary signal processing software does not account for the physical reality of the original source. In most applications, the mathematical models used here provide a synthetic template that includes both dynamic and static characteristics for signal description, which are almost always merely mathematical descriptions of the trajectory of the observed signal (Picci 2003). The use of noise removal algorithms in audio restoration is often represented as a neutral or objective process, but this is not the case. It is suffused with the subjectivity of the restorer, who cannot evade their responsibility here. Any given software package implements only one of many possible models of the sound. While the restorer does not engage in specific acts of software engineering, they have chosen to use one piece of noise removal software rather than another and must set its parameters, thus shaping the final version of the audio that the software produces.

The analysis of musical recordings must consider a variety of sources, including instrumental and electronic sound, as well as the kind of information that would come from traditional music analysis in musicology or music theory. Textbooks about signal processing tools and the software that implements them are common (e.g., Hartmann 1998; Klapuri and Davy 2006; Beauchamp 2007; Havelock, Kuwano, and Vorlender 2008), but such writings do not consider the underlying theoretical questions about the nature of music restoration that such work necessarily entails. From the standpoint of music psychology and music acoustics, only a few of the existing musical feature extraction algorithms really match with human auditory perception or account for the physical production mechanisms of music sound (Bader 2013). In Kantian terms, we could say that, in the specific field of restoration, algorithms for audio signal disturbance removal are blind without a historical-musicological analysis, just as the latter would be void without the operational tools expressed by the algorithms.

FROM PRESERVATION TO CRITICAL EDITING

Over the years, the international archival community, along with the restorers and researchers who produce critical editions of recorded music, has provided diverse approaches and solutions to the problems discussed above. Increasingly aware of the need to digitize audiovisual documents, libraries and archives worldwide have defined specific standards to undertake this work, in accordance with the needs of repositories and with the support of universities (Casey and Gordon 2007). This work has been carried out at such large institutions as the Library of Congress in Washington, DC (Hirtle, Hudson, and Kenyon 2009), the British Library's Sound Archive (Day et al. 2014), and the Institut national de l'audiovisuel in Paris (Gayou 2013; Bachimont 2017); archives that house the papers of individual composers, such as the Luigi Nono Archive in Venice (Cossettini 2009); and concert halls that preserve the memory of their seasons, such as the Teatro Regio in Parma (Cossettini 2015).

Through its reports, the International Association of Sound and Audiovisual Archives (IASA) has raised awareness of the need to establish ethical principles for the preservation of audio documents. It discourages technologically inappropriate approaches to restoration, including the use of subjective choices by restorers that are not technically compliant with the current level of knowledge regarding active preservation (Schüller

2005; Bradley 2009; Schüller and Häfner 2014). Important restoration projects that follow the establishment of the IASA guidelines include Europeana (Europeana Foundation, n.d.), a digital library that brings together materials previously digitized by institutions from the twenty-seven member countries of the European Union. The IASA's guidelines have been of great value in providing basic training to archivists and allowing them to take charge of the audio collections under their care. Nevertheless, this work is not without its difficulties. Among the practices recommended under item 6 of the 2005 edition of the IASA's guidelines (IASA-TC 03) is the following: "If several copies of a sound document are available, the best must be selected for the further preservation of its content" (Schüller 2005). This position is confirmed and underscored again in the 2009 guidelines (IASA-TC 04), where a "best copy" is defined as the result of selecting from among "copies of the same generation" (Bradley 2009, item 5.4.2.1). The report does not define "generation," which leads us to the conclusion that it is meant in a generic sense. It is thus worth trying to gain insights into the IASA's recommendations.

Consider, for example, the production of phonograph discs, which is similar in many regards to that of printed books. Since the 1980s, the scholarship on textual bibliography has examined the meaning of the term "copy." Here, a copy is seen as the outcome of historical processes of creating similar or identical objects of a defined group (see Fahy 1998; Dane 2009). Textual bibliography has, therefore, tied the notion of "copy" to the processes involved in an editorial project. Thus, several different "copies" cannot be dismissed simply as products of the same "generation." Rather, to draw on the language of book publishing, a copy is something similar to an edition (i.e., copies of a book printed from the same typesetting), impression (copies of a book printed from the same plates in an edition, but at a later date), issue (copies of books within the same impression and offered to the market at different times), or state (copies of books that have corrections made in the middle of printing an edition). Copies of the first issue of an edition of a book would have a meaning and a conceptual (and economic) value different from that of the second issue of the same edition. Similarly, with phonograph discs, various copies could be produced and distributed from a master disc or matrix. For instance, beginning in 1901, the Victor Talking Machine Company and the Gramophone and Typewriter Company exchanged matrices, resulting in the production of copies from the same matrix, and therefore from the same "edition," but belonging to different "impressions" or "issues." All of this suggests that preserving only the "best copy," as per IASA guidelines, regardless of the stage of production from which that recording came, would result in a distorted or partial image of the disc's entire history. In defining a "best copy" as the one containing the best signal, the IASA's guidelines therefore promote, for merely technological reasons, a skewed representation of the work's history.

In the world of music composition, IASA ethics are irreconcilable with electronic music production, and there are several reasons for this. First, every variant or version, regardless of its "quality," has a value of its own, as well as its own distribution history. Second is the issue of "vulgates" (original or "authorized" versions). Often, the "best copies" do not come out of the studio archive where they were produced. Rather, works are spread through rented copies, restorations, and recording editions—that is, versions that not infrequently differ from the oldest source. Further, an audio master could, for various reasons, be affected by corruptions but, unlike one of its "better" copies, still contain valuable information about its editing (such as additions or interpolations of blank tape). Masters may also be accompanied by notes on the physical recording artifact itself that are not transcribed on the copy but were nonetheless essential to the compositional process of the author. Such notations can be essential for recovering the synchronization of vocal and instrumental parts when the work is played in concert. (See the case of Luigi Nono's *Al gran sole carico d'amore*, discussed below). Applying IASA ethics guidelines to works of electronic music would thus have an insidious effect on the preservation and restoration of this music. Doing so would introduce a selection criterion unsupported by documentary evidence for choosing a "best copy" of an author's work and harm the entire canon of twentieth-century electronic music, a heritage that is characterized by art's mechanical reproduction.[6]

The restoration of electronic music is further complicated by the fact that some music pioneers—for example, composer Iannis Xenakis—modeled their compositional procedures on stochastic mathematical processes, such as those described by random walk theory (which seeks to account for the ways that randomly moving objects may be displaced from a starting point), Markovian sequences (in which the probability of certain events depends only on previous events), and Brownian motion (the random movement of particles suspended in a medium), or on intentionally generated noise. Such compositional processes undermine the models that are at the base of the noise detection techniques used in today's audio restoration algorithms. Those involved in restoring this type of music often feel that they are experiencing a kind of cultural impasse, a vicious circle in which the foundations of the technology at their disposal belong conceptually to the very forms of musical experimentation that underlie the music they are trying to restore. Here, art and science converge so closely that there is no alternative to using restoration methodologies that are sustained by historical and musicological knowledge.

In analyzing sources, we must also attend to the contribution of genetic criticism (Donin, Grésillon, and Lebrave 2015; Appel 2016; Donin 2018). In such work, literary scholars distinguish between explicit (i.e., intentional) metatextuality—in which a writer directly acknowledges a work's connection to other works—and implicit (unintentional, contingent) metatextuality, where the connections between a given text and other ones only surface in the reading, contextualization, and interpretation of that text. This latter form of metatextuality contributes to determining the phenomenology of a tradition. This distinction can also be made with regard to audio recordings: intentional and unintentional alterations (a kind of distinction that Schüller himself discusses), production and reproduction (i.e., reading) errors, controlled and uncontrolled noises, and signals of various kinds (Orcalli 2013). It is precisely because implicit metatextuality, and thus the phenomenology of a tradition, is forged in the reading and interpretation of texts (Appel 2016) that it is essential in the world of electronic music to be able to "read," distinguish, and recognize metatextuality as such. Further, one must possess the technological skills required to use the media that produced a document or the track, skills not always possessed by those who manage recorded music archives. The significance of, and need for, systems-based interpretive approaches aimed at reconstructing the human and technological universe in which a work was created is demonstrated in such publishing initiatives as the Bernd Alois Zimmermann-Gesamtausgabe (which is restoring the electronic music of composer Bernd Alois Zimmermann; see Pasdzierny 2020) or efforts conducted at Universal Music-Casa Ricordi to restore a broad range of works from the heritage of electronic and mixed music captured on analog and digital audio, as well as computer media (for work already done on the electronic and mixed music of Luigi Nono, see Mazzolini and Cossettini 2024).

The study of the origin of an electronic work and its process of transmission in time and space, as well as the analysis of the media and recording systems involved in its emergence, allows us to understand the genesis and evolution of the work in all its variants. Bruno Maderna's *Dimensioni II/Invenzione su una voce* and its reprocessing on the album *Hyperion* are emblematic in this regard. The compositional idea implemented in this work is based on a new interpretation of the relationship between the composer and the electronic equipment that the composer uses: working on the piece, Maderna soon realized that the electronic technology he was using did not necessarily lead to *opera aperta* (lit. "open work," the artist's decision to leave the arrangement of some constituents of a work to the public or to chance; Eco 1989). Rather, it paved the way for the creation of a new form of "work in motion" and of a new connectivity among differing works. This perspective (see Vidolin 1989) is supported by an analysis of nine archival sources for *Dimensioni II/Invenzione su una voce*, which reveals the surprising number of variants that the composer developed (see Cossettini and Orcalli 2015). The audio documents that were given the title *Dimensioni II/Invenzione su una voce* show that Maderna was constantly reworking this piece, from the time it was first performed in 1960 till 1972. A comparison of the waveforms of these recordings (Figure 1) demonstrates the special attention Maderna paid to this work, including the many adjustments he made to the duration of tapes of it in various concert settings, which were also affected by the increasingly less assiduous presence of the singer Cathy Berberian in its production, and the many changes he

made to the name of the work (Badocco 2017). Over time, Maderna went back to parts of the composition and added them to his later piece, *Hyperion*, *Ages*, *Tempo Libero*. In his expunction of individual parts from the work and the many permutations he made to their order, as well as in his redistribution of them at different points in the montage of other works, the original identity of the piece disappears completely, as does the traditional idea of the uniqueness of a musical composition.

The study of audio sources provides information about the composers' *modus operandi* in the music laboratory. Abandoning the idea of a "unified" and "standardized" work allows for the preservation and study of recorded music in all its variants and complexities, which is essential if we are to maintain the canon of twentieth-century electronic music in the Western art tradition. Take, for example, Luca Cossettini and André Richard's restoration of the electronic parts of Luigi Nono's *Al gran sole carico d'amore* for the 2009 Salzburg Festival (discussed in Cossettini 2020). The work of restoring this piece encountered two difficulties: in addition to the problem of re-actualizing the piece's political message, Cossettini and Richard had to address the question of interpreting the many sources for the work (e.g., scores and magnetic tapes). In the literature on *Al gran sole carico d'amore*, a distinction is made between two versions, one dated 1975 and the other dated 1978. These correspond to two different productions of the piece at La Scala in Milan, with the composer himself supervising sound direction for both productions. A study of the composition process for this piece shows the painstaking review that Nono made of both the audio materials and the manuscript or printed musical texts for the work: tapes of the piece were copied several times, and their content was "re-edited" through physical interventions directly on the tapes

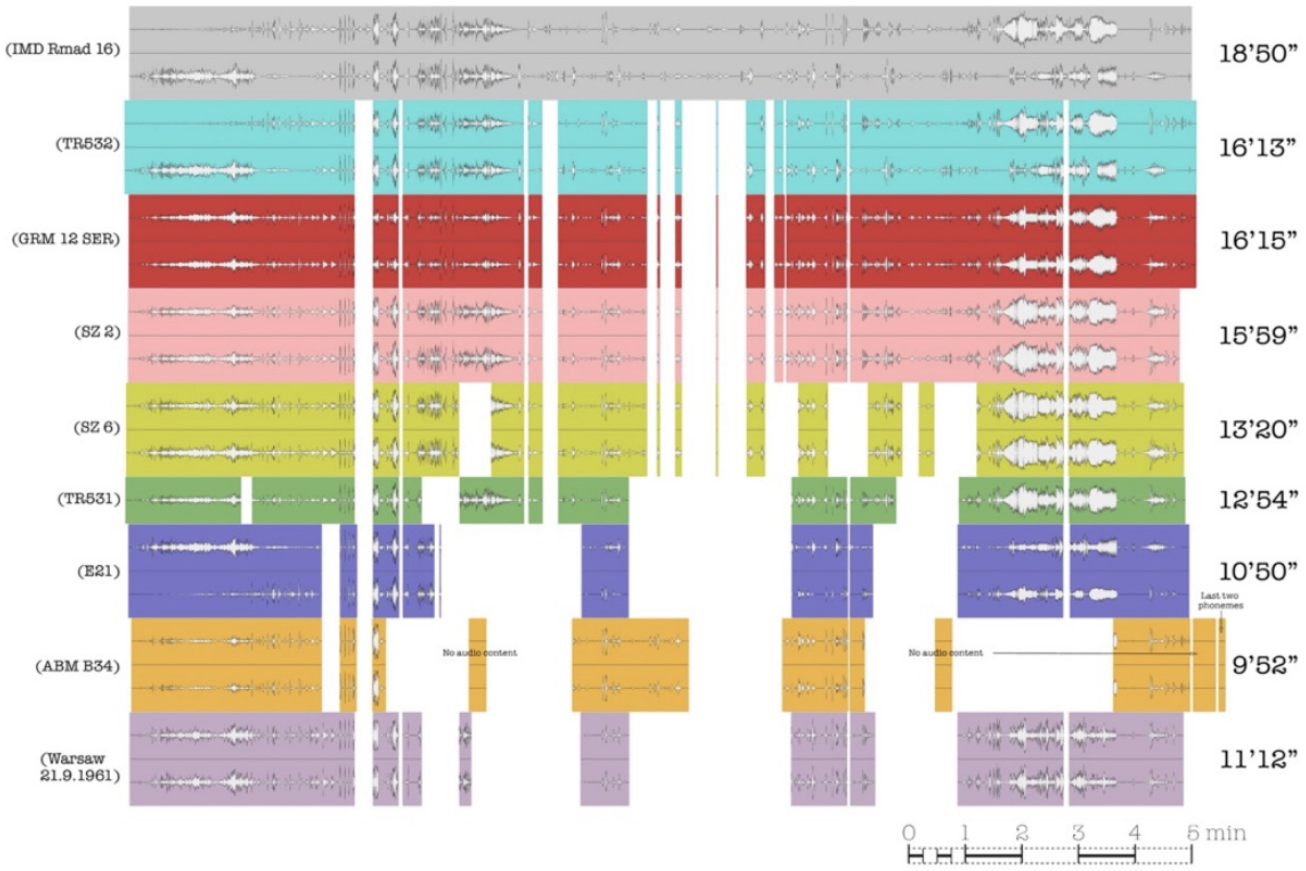

Figure 1. Comparison of nine significant archival audio sources of *Dimensioni II/Invenzione su una voce* by Bruno Maderna. From top to bottom, the archival sources for the waveform diagrams are IMD-Darmstadt, Tempo Reale-Firenze, GRM-Paris, Suvini Zerboni-Milan (SZ 2 and SZ 6), Tempo Reale-Firenze, RAI-Milan, Archivio Bruno Maderna-Bologna, and the Warsaw Festival.

themselves. Considering all of this, we might say that the score was full of notes, corrections, deletions, and replacements. The large number of variants in the text and the sound fabric itself is evidence of a continuous process of source adjustment that, almost uninterruptedly, joins the two versions: in restoring the 1975 version, Cossettini and Richard had to extract it from underneath the stratifications that led to the 1978 version, and assigning the various surviving electronic parts to one version or the other was an undertaking full of ambiguity and uncertainty. The greatest difficulty in this process derived from the fact that instructions in the two published scores about which electronic parts should be used, when they should begin, and their duration were totally insufficient; furthermore, there was no indication in the scores regarding sound direction. Here, the texts and audio documents used by Nono for the 1978 staging were indispensable for understanding the relationship between the electronic and instrumental parts in the work. By reviewing the composer's sound direction notes, Cossettini and Richard were able to determine how the two components were synchronized: a draft for the score of the second version, kept today at the Luigi Nono Archive in Venice, shows the composer's fine-tuning of entrance indications on the tapes, which were not included in the published score. The magnetic tapes from the Italian broadcaster RAI have a set of measure instructions, which were revised several times. These instructions, though specific to the 1978 staging, today show how the dialogue between the orchestra and the electronic parts should be interpreted (Figure 2).

In reconstructing the electronic parts of *Poème électronique* by Edgard Varèse, Kees Tazelaar faced similar problems, which are typical of the montage operations associated with works that use analog magnetic tape recorders. Here, problems in calibrating the running speeds of the piece's tape recorders led to a loss of

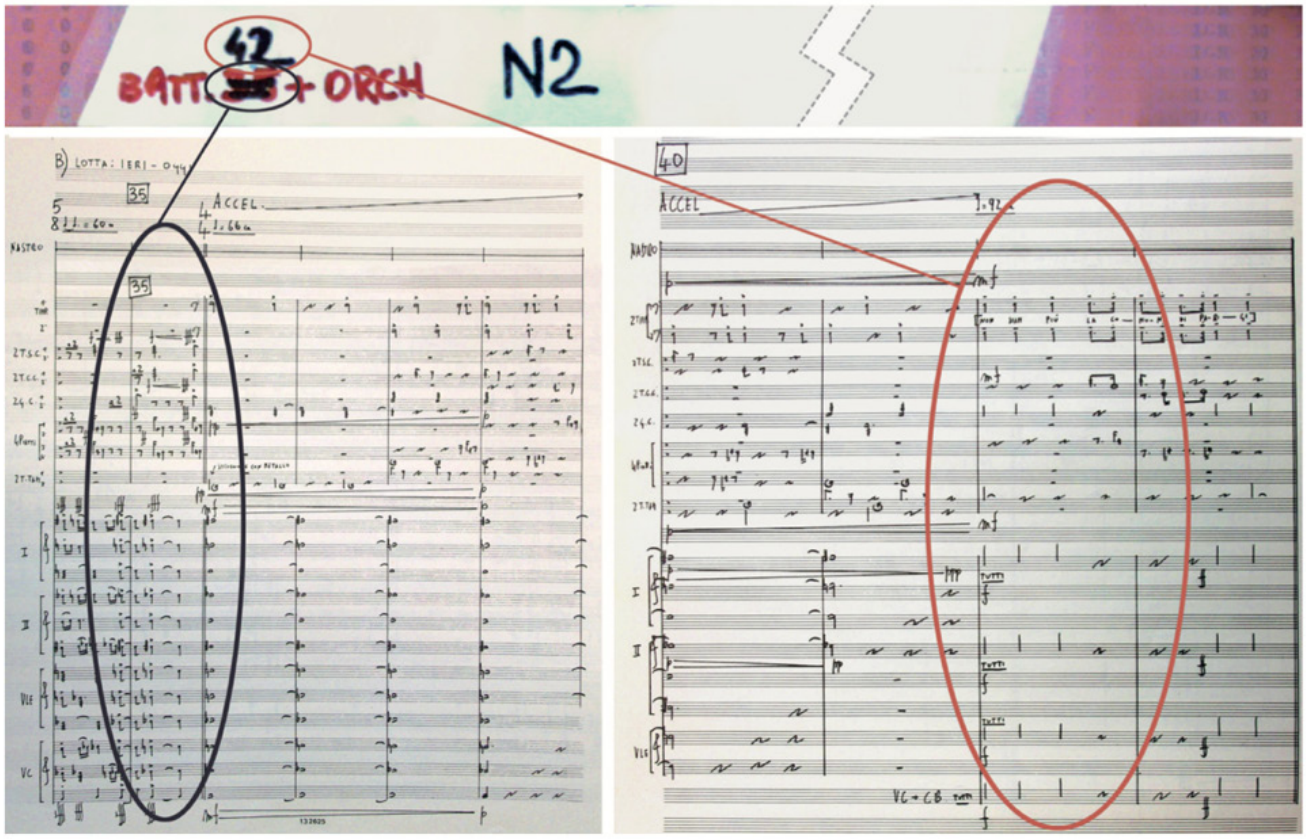

Figure 2. Above: measure instructions for Luigi Nono's *Al gran sole carico d'amore* found on magnetic tape Q31 (RAI-Milan). Below: the published score of Luigi Nono's Al gran sole carico d'amore, measures 34–43, with the revisions indicated in the circled passages. Copyright Casa Ricordi (1977). Used by permission.

synchronization among its parts and had a substantial impact on the structure of the work. An article about the restoration written by Richard Dobson, Tazelaar, and their colleagues notes that "when using the clicks [in the recordings] to align the tracks, one immediately notices that the original machines were not completely identical in their tape speeds" and that the durations of the single tracks were different (Dobson et al. 2005, 39). As a result, the durations of the various parts differed from each other. To restore the correct alignment of the sound events, it was thus necessary to use other multitrack sources, including the "perfomaster" (the mono soundtrack of a video copy of a film of a performance of *Poème électronique* that was supplied to Tazelaar by the archives of the Philips corporation) and a Columbia Gramophone record of the piece. In a book about Philips's role in the development of electronic music in the Netherlands, Tazelaar (2013) delves deeply into the history of *Poème électronique*, including its production in the recording studio and exhibition at the Philips Pavilion at the Brussel's World Fair in 1958. In so doing, Tazelaar underscores the importance of the technical experts from Philips who worked with Varèse (including Willem Tak, Simon Leo de Bruin, Jan de Bruyn, and Anton Buczynski) for the creation of this piece.

Poème électronique only existed in the form that Varèse and his collaborators originally intended from May 20, 1958, to October 19 of that year, when the fair ended and the Philips Pavilion was dismantled. At the time, a thorny question was posed regarding the work's survival: how could the memory of such an experience be passed on to future generations? Varèse came up with a "musical" solution by curating an edition of the work on LP record. This was comprised of a stereophonic mix of the original tapes, to which reverberation was later added, possibly to compensate for the absence of the sonic effects that the space of the Philips Pavilion had on the listener's experience of the piece. However, the LP was not the only way in which the composition was to live on. As one of the most celebrated pieces of electronic music in history, *Poème électronique* soon featured in concert programs dedicated to contemporary music. Separated from its original setting, performances of the piece on concert stages radically upset the original, underlying compositional idea for the work. Following advances in digital audio and virtual reality, ambitious projects have recently been undertaken to reproduce the original spatial audio experience of *Poème électronique* (Lombardo et. al 2009), and these are not the first attempts at reconstructing these features of the work. In the 1960s, Frits Weiland, a composer and technician at the studio for electronic music at the Plompetorengracht in Utrecht drew on four separate tapes to produce a quadraphonic version of the work, using spatialization techniques consistent with the technological conditions of the time. (The Plompetorengracht was later renamed as the Institute of Sonology and was the site where the original master tapes of *Poème électronique* were then stored.) Weiland's version, which "was from then on referred to as 'the master' of *Poème électronique*" (Dobson et al. 2005, 30), has now been restored (Cossettini 2017) and can be used in individual performances by paying a fee to its publisher, Casa Ricordi.

BEYOND PHILOLOGY? CONTEMPORARY APPROACHES TO EDITING SOUND DOCUMENTS

Before discussing ideas and terms from philology and biology that are useful in thinking about reissues of historical electronic music, it will be useful to define a couple of types of reissued texts. In literature and in musicology, a *genetic edition*, rather than providing a stable text of a given work, is interested in variants and the genetic path of its composition. It is as much interested in rejected as accepted variants, with the aim of reconstructing the dynamics of the text—that is, its traces and its compositional process. It is an act of interpretation and reconstruction and only to a limited extent a form of text constitution. A genetic edition is dynamic; it cannot be adequately realized in printed form and must be published as a hypertext or in other interactive media. A *historical-critical edition*, on the other hand, is a closed product (i.e., an opus) centered on the work and not the author or their compositional thought. It claims to constitute a text of the work and uses a primary source to present editorial interventions. Editors who develop either genetic editions or historical-

critical ones accompany their text with a report that explains the work that they have done. Ultimately, the editor's publisher decides whether to release a hypertext genetic edition, which accounts for the work's historical complexity (Darnton 2009; Farkas 2004; Cossettini 2021), or follow the textual tradition and release it as a historical-critical edition.

Defining the differing approaches to a text that an editor may take (Schillingsburg 2001), classical philology can help music scholars understand the nature of editorial work, and we have adopted ideas from that discipline in developing a classification system for the restoration of sound documents (Orcalli 2006). A *preservative* approach considers all the information presented in a document and treats that document as an artifact; in other words, it aims to preserve the artifact's documentary unity. The process of re-mediation here uses digital media to represent, immediately and with complete transparency, the information and material characteristics of the original document as it has come to us. A *documentary* approach focuses on a document's form, on the interplay among its sound fabric, the production equipment and techniques used in its creation, the compositional practice involved in developing the work, and authorial intent. Seeking to create an accurate version of the work, the editor includes with the final edition an accompanying review of the sources they consulted. For the *reconstructive* approach, the central concern is intellectual responsibility. Based on a study of a work's genesis, this approach seeks to recreate a sound fabric that reflects, as far as possible, the intention of the author. It achieves its goal through a *collatio* of witnesses and by placing the work in the context of its musical tradition and the historical moment in which it emerged. Many of the techniques used in literary philology have parallels in music editing; for example, both employ insertion, deletion, and substitution to deal with textual variants. Where the difference between the tools of textual philology and those of music editing is most marked is in multitrack recording, where issues relating to synchronization, live capture, and source separation emerge (Vincent, Virtanen, and Gannot 2018). These call for the development of new critical and analytical techniques.

In a media context characterized by big data and deep learning, the restorative approaches adopted by editors working for Internet music publishers today seem to have abandoned both "nostalgia" (the desire to reconstruct the original version of a work) and what we could call the sociological approach (Orcalli 2006) to restoration,[7] which characterized a great deal of past work in the recording industry. Instead, publishers are embracing practices of transformation and recombination, where any reuse and reinvention of music is possible. This purely aesthetic approach, which considers the potential of the work in relation to both its use by the recording industry and its performance, is aimed at producing a commercial, as opposed to a genetic or even historical-critical, edition. Here, the composer's and producer's immediate access to a vast array of sonic artifacts through sampling and other techniques has produced a kind of neuro-aesthetic: we have entered the age of sound, rather than music, where what matters is the composer's or listener's emotional relationship with auditory phenomena.

Since the nineteenth century, work in linguistics on the transmission of language has brought the paradigms of evolutionary biology and genetics into philology (Cavalli-Sforza 2000). Extending the approach found in Shannon's information theory, engineer Gérard Battail, in *An Outline of Informational Genetics* (2008), makes a distinction between "replicating" and "regenerating" invariant features in the transcription of genetic code (the process of copying a segment of DNA into RNA). Replication produces a copy that matches the original genome as closely as possible, ideally doing so in an identical manner. Regeneration, on the other hand, refers to a rewriting of the genome's message. Here, the new message fits within the strict constraints of the original genetic code and is as close as possible to that code, though it may include errors. Unlike replication, regeneration does not produce a new message that is identical the original one. Nevertheless, it is true to the original genetic code, when understood as a set of constraints. Regeneration is a useful concept for thinking about reissues of historical electronic music, because it raises the prospect of a critical editing practice that, by virtue of the presence of a compositional model that can be formalized as a series of constraints, allows for restoration work on an analytical basis.

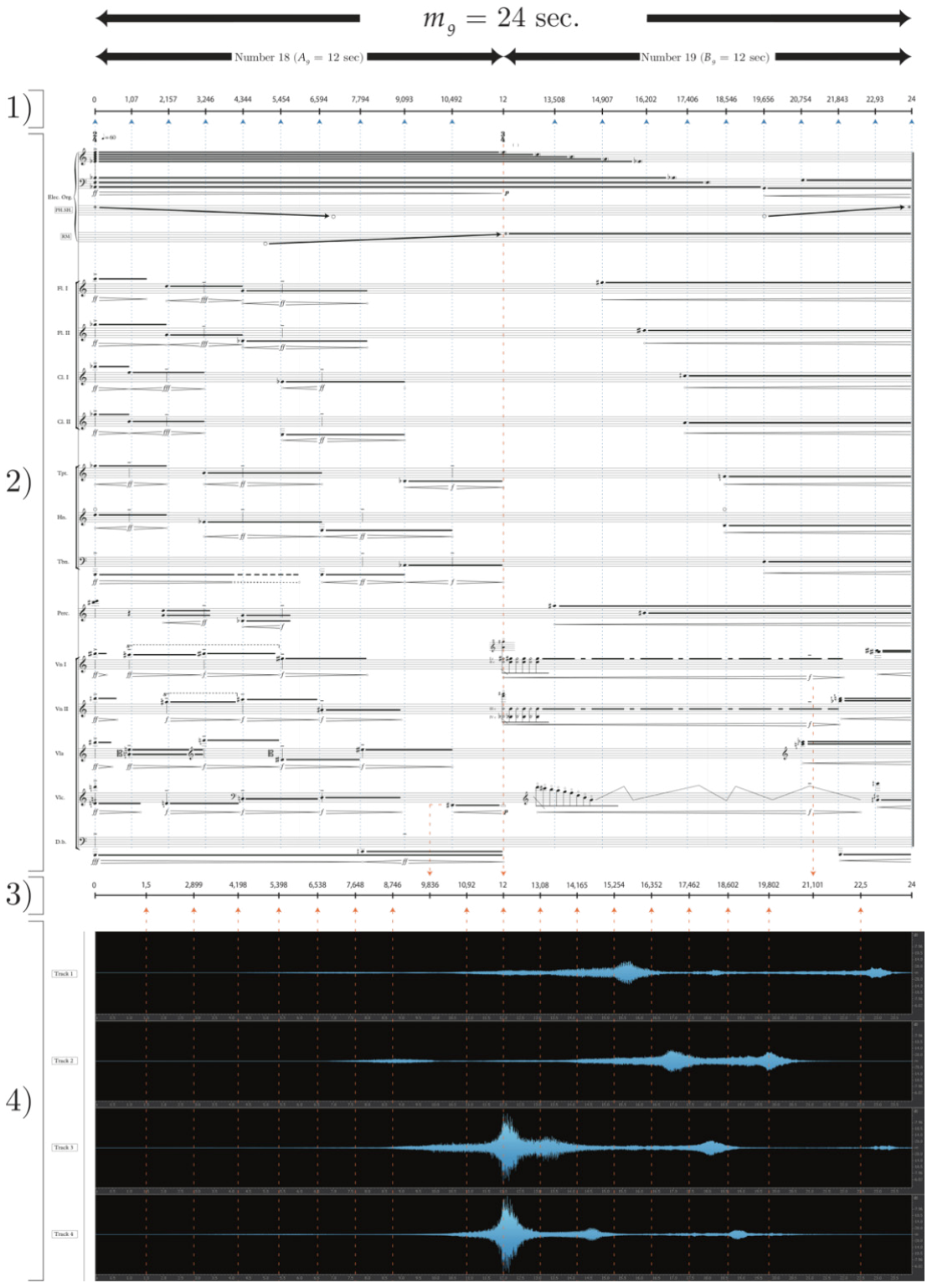

Figure 3. *Jour, Contre-jour* by Gérard Grisey, section 9, rehearsal numbers 18 and 19. The figure illustrates the relations among: the timings for the instrumental part, which were derived from the compositional model (and which, as indicated in the left margin above, is the first horizontal block of the figure); the rendering of the parts in standard music notation, re-elaborated from the score (the second horizontal block of the figure); the timings for the electronic part, derived from the model (the third horizontal block of the figure); and the signal on the 4-track tape (the fourth horizontal block of the figure). Graphic elaboration by Alessandro Olto. Used by permission.

The regenerative editing of audio documents is extremely demanding in terms of processing complexity. The restoration of the electronic part of *Jour, Contre-jour* (1978) by Gérard Grisey is a case in point. Due to the poor quality of the original 4-track audio recordings of the work that were available for live performance, as well as the fact that the mix on those recordings could not be altered, a reconstructive approach to restoring this music was impossible (see Cossettini and Orcalli 2018). However, it was possible to use regenerative techniques to restore those parts, and this was achieved by (a) reconstructing the compositional model of the work according to Grisey's original sketches (Figure 3); (b) consulting the mixing patterns provided by Folkmar Hein, the original recording engineer for the piece; and (c) having access to the 8-track premix recording of this work, which was kept at the Elektronisches Studio of the Technische Universität in Berlin. The process of restoration then proceeded by first digitally remastering the 8-track tape; next, the resources of digital editing were used to synchronize the various sound events in the work, with the "timing" taken from the compositional model developed earlier. The tracks were then mixed, based on Hein's handwritten instructions. As a result of all of this, the tasks of observation, recognition, and restoration were fulfilled and unified through the regenerative approach.

Resynthesis is another approach to the restoration of analog electronic works, and it is very different from regeneration. Exquisitely organological, resynthesis aims to model the original instruments used in a piece and digitally reconstruct it from sketches, compositional models, or realization schemes. This is particularly useful for works by composers, such as Karlheinz Stockhausen, who placed theoretical reflection on compositional models upstream of the compositional process. Such an approach to producing reissues of historical electronic music is especially preferred when no preparatory or multitrack audio materials, such as those available for regenerating Grisey's *Jour, Contre-jour*, have survived. However, there are limits to this approach. The transition from analog to digital synthesis is not anodyne, as the production system for analog sound differs significantly from that of digital sound. (Think, for example, of the way that signal-to-noise ratios differ in the two domains or of the nature of the sonic impulse and its control in analog versus digital synthesis.) Further, as we have seen in our discussion of the restoration of works by Varèse and Grisey, the performative element in the studio (e.g., the work that the composer or engineer does to mix the various parts of a composition or add signal processing), which is constitutive of the sound itself, produces a distance between the model and its realization, and this often becomes an integral part of the work. Indeed, the desire to modernize the sound of their works is quite natural for composers. It is undeniable that the resynthesis of compositional models, which has been successfully adopted in many conservatories and music institutions, has didactic value (Vidolin 2002). Given its limitations, though, this practice should have a critical counterpart in approaches that highlight the historical condition of the media that were involved in the music that is being restored.

IS THERE AN ARCHAEOLOGY OF DIGITAL MEDIA? OR, WHAT'S ON STAGE?

The 1990s was a period in which a critical approach to media studies known as *media archaeology* (in German, *Medienwissenchaft*) attracted wide attention. Media theorist Friedrich Kittler (2002, 2009, 2015), a representative figure of this movement, argued that recordings, especially sound recordings, capture the full actuality of unique, material events in the world, regardless of what humans can see or hear, and transform them into electronic and digital signals. Thus, for Kittler, there is continuity, rather than rupture, between analog and digital media, despite the heterogeneity of the material processes at work in the two domains. What is inscribed in media is always an encoded real, regardless of the medium used to write it. One can glimpse in Kittler's ideas a continuity with Shannon's theory, as Kittler does not account for the material component of message transmission (i.e., the physical medium of communication). This is in contrast to Norbert Wiener, the father of cybernetics, for whom information is never totally divorced from the technical system that transmits it, nor is it unrelated to the physical reality of the observed phenomenon. By contrast, Shannon focused his research on problems of message coding

and therefore treated information abstractly as a pure succession of symbols. Through the digital representation of signals, Shannon achieved a theory of encoding that reinforced the idea that the message is independent from its medium and the transmission system that sends it. (The exception to this is Shannon's consideration of the noise that the medium [i.e., the channel] produces and the type of encoding that a transmission system uses—that is, the system's level of quantization.) The idea that information is separable from its medium has implications for the nature of information processing. The operations of a universal Turing machine (that is, an information processing system, such as a computer), the electronic processor, are projective transformations: in theory, a processor takes a series of symbols as its input and uses rules to produce an output. In this context, the properties of the second series are produced by transformations of the first series. But because information cannot be fully separated from its medium, transformations involving time cannot be produced without leaving some residue. According to information theorist Robert Escarpit (1976), from the point of view of Shannon's theory, the idea of fixing information in terms of time is paradoxical, because information is, by definition, associated with the degree of uncertainty of an event.

If, as we have suggested, information cannot be separated from its medium, then the restoration of audio documents that were created with music technology from the past cannot, in any simple or direct way, be achieved by newer technologies. Scholars restoring musical works created at the dawn of digital technologies—especially in that period when hybrid analog/digital synthesizers were common and early computer synthesis systems were used—have faced problems, not unlike those highlighted so far, that stem from the use of legacy sound production systems (Vincent, Bonardi, and Rousseaux 2012). For example, in his rewriting of John Chowning's *Stria* (1977), engineer Matteo Meneghini (2002) faced the problem of translating code written in the SAIL programming language into something that contemporary computers could understand (see also Zattra 2007). Likewise, to save the electronic parts of Hugues Dufourt's *Saturne* (1978–1979), musicologist Yann Geslin (2013) engaged in a massive project of organological reconstruction, virtually rebuilding the entire electronic instrumental apparatus of the original work, which at that point had largely been abandoned, either by using the instruments of the time (Yamaha synthesizers) or by adopting frequency modulation techniques.

The freshness of philosophical and methodological reflection in the field of audio restoration and reissues can be seen in the development of new terms and concepts there and the plurality of solutions that scholars are proposing to the problems that they encounter in their work. Exemplary in this regard is musicologist Laurent Pottier's (2013) restoration of Chowning's 1988 piece *Turenas*. Pottier proceeded from a concept of *régénération* that differs from that informing the restoration of Grisey's *Jour, Contre-jour*.[8] The result of this work was four approaches to the task of restoration, which led to four different versions of the piece. In one, *Turenas* is "reduced to 4 minutes, without the central parts.... This version uses three MIDI keyboards, a Kaoss Pad, and a computer running Max/MSP." The second involves "a 4-track reconstruction of the piece using CSound (V2a) [a computer programming language designed for electronic music composition] and Max/MSP." The third version, named *Turenas Live*, uses "four percussionists and a real-time device." The final version, which was named *Turenas Live II*, "used score recognition…four percussionists and a real-time device" (Pottier 2013, 145).[9]

The rise of computer-assisted composition has only exacerbated the challenges of restoring audio documents. This development has made clear that even processors, programming languages, and digital storage media will (and already have) become obsolete. In this context, we must develop new diasystemic strategies for the preservation and restoration of native digital works and new ways to adapt them to concert life. Emblematic in this sense is the work of musicologists Alessandro Olto and Pottier, who in their analysis and restoration of Fausto Romitelli's *EnTrance* (1995) had to confront an arsenal of technologies from the past, including samplers and programs for formant wave function synthesis and variable wavetable synthesis in programming languages and software environments such as LISP, Patchwork, Csound, and Pro Tools (Olto 2017; Olto and Pottier 2020). This work also included the physical restoration of a Yamaha SY 99 digital synthesizer. Similar problems must also be addressed with regard to the preservation of electronic music "in real time" where the generation

of sound with electronic devices (analog first and digital later) occurs directly during the performance. For more than a decade, IRCAM (Institut de Recherche et Coordination Acoustique/Musique) has been developing database systems designed to archive, preserve, and document these types of work in its collections. The outcome of this project is the Sydney system for "archiving and documenting the technological aspects of all electronic pieces created at IRCAM, in the technological state of their creation or their last performance"[10] (Lemouton and Goldszmidt 2016, 102). Preservation and restoration projects like these demonstrate the limitations of Kittler's intellectual approach, which rejects the important differences between various kinds of media.

LIVE ELECTRONICS

Live electronics opens other problems for the restoration or reissue of musical works, and these have to do with the peculiar conception of sound that results from encounters with real-time sound processing systems. The editorial issues arising from the relationship between traditional instruments and electronic ones are exemplified by the recent reissue of Luigi Nono's *Prometeo*. Commenting on the project, the general manager of Casa Ricordi, Marco Mazzolini (2021), states that "while it is true that the nature of the edition is eminently practical and not critical, it is equally true that, in their work evaluating the text, the editors have availed themselves of a methodology similar to that which is current in the field of critical editions, due to the specific editorial issues raised by the score of *Prometeo* (and which, incidentally, are common to all of Nono's scores involving live electronics)" (317). In the 1980s, Nono had an arsenal of electronic instruments at his disposal; today, these instruments belong to the history of technology, and the restoration work on this piece took place in this new technological environment. Sound restoration for each instrument required attention to a number sonic parameters. This included the use of particular kinds of microphones and their specific positions relative to the instrument in questions, as well as the use of devices like harmonizers, reverb units, delay effects, filters, vocoders, gates, and so forth. A prominent feature in the staging of *Prometeo* is the halaphon, a digital device that controls the movement of sound via loudspeakers distributed throughout a space. In an essay accompanying the score of this work, sound engineer André Richard explains that "in *Prometeo*, up to four independent cyclic movements of sound may be realized, each with different durations. Mostly, the full cycle of a movement of sound takes place at regular intervals over four loudspeakers [controlled by the halaphon] and continues without interruption (*da capo*) until a new program is launched.… In the parameter list reproduced further below [in the technical apparatus], the duration of a full cycle, for each movement of sound is specified. These durations are to be understood as default settings" (see Richard's performance notes in Nono 2021, 417). Without an understanding of the original technology, it would be impossible to create a useful new edition of this work.

The distance between past and present technologies and the absence of the composer and his performers forces scholars restoring and reissuing electronic music to draw up programming lists and parameter matrices for controlling the sound processing in the discrete domain of the computer. In this context, we must keep in mind Benjamin's (1928) dazzling observation that "the capacity of the imagination [is] the faculty of making interpolations in the infinitely small" (46).[11] Thus, in the passage from the notational system of the score to the realized sound, for example, the temporal continuum of the music opens up to infinite possibilities of interpretation. In the dense textual nexus of the score, one must discover the minimal cavities in which an interpretation that knows how to produce meaning takes refuge. And in the case of a composition like *Prometeo*, Benjamin could not have imagined that the infinite interweavings of the musical work would not only involve a textual nexus but also include interweavings of a complex feedback network, modeled on the cybernetic paradigm, in which composers like Nono conceived the system of their work.

CONCLUSIONS

Scholars engaged in preserving and reissuing works of electronic music are facing old problems in new and complex forms. In this context, we want to suggest that the philological and technical issues that we have discussed above ultimately depend on the composer's, editor's, or engineer's conception of the authenticity, identity, and integrity of a musical work. Further, the issue of noise and its place in the music's technical system is always a central concern, as are the different and ever-changing interfaces and modalities that allow us to access the audio. In differing ways, these problems relate both to documents of digital origin and to documents derived from analog carriers (Orcalli 2020). In conclusion, we therefore offer three postulates for the preservation, restoration, and reissuing of audio documents and works of electronic music.

First, we want to suggest that the transmission of audio documents depends on the operation of what philologist Cesare Segre (1981) referred to as "diasystems." Writing about literary texts, Segre used this term to refer to the interaction of two semiotic systems in a written manuscript—the linguistic system of the author and those of the editors or copyists who filter the text through their own code. Each editor or copyist uses a personal language system, which encounters that of the text during the transcription process. The more attentive editors or copyists will try to leave the text system intact, but it is impossible for their system not to prevail in some respect; given that the competing systems are connected to their historical contexts, Segre observes that it is as impossible for any editor or copyist to renounce their own system as it would be to deny their historicity. With regard to the re-mediation of audiovisual documents and the transmission of recorded music, this means that the encounter between the system on which the work is recorded and the system of the new medium always produces a metamorphosis of the original work.

Second, we argue that attempts to identify and preserve audio documents according to a "best copy" standard denies the historicity of audio documents and ignores the relativity of our knowledge with regard to them. Improvements in technology and advances in our knowledge of original documents can infuse with significance data formerly believed to be nonessential. For example, noise can become signal, and conversely, what is deemed to be a useful signal in one context can be read in another context as noise. As a result, it is imperative not to make selections of documents based on a presumed best copy, which in another time and cultural context could be derated. Greater awareness of the historicity and the comparative value of copies of musical works can be achieved most effectively through the international exchange of information between archives and laboratories that are active in the audio field and beyond: bringing together experiences and practices from differing domains of preservation and restoration may lead to useful comparisons.

And finally, musical works that take the form of recordings are inseparable from their media transformations. The electronic work is always the product of a compositional process of transforming a plurality of media, and audio documents are therefore the projection of technical-theoretical choices made by the composer. Making an analogy to the hologram (Morin 1977), we might say that the documents pertaining to the work are diffractions of compositional thought on a medium and, when taken together, constitute a whole. This implies that the reissue of the work requires multidisciplinary expertise. Today, the vast number of instruments and electronic devices used in electronic music necessitates handling different types of sources and using different types of software to analyze data. The multiplicity of creative practices in electronic and mixed music, the complexity of materials and forms, and the problems of interpreting sources and understanding devices bring differing media into play (Bonardi et al. 2017). The writing of an electronic score and the capturing of artistic processes and performances in multiple spaces of creation (the space of the studio in which the electronic part is conceived, the space where audio signal and computer codes are replicated, and the space of the concert) are all dimensions of music that cannot be reduced to a single media sphere. This conceptual and operational complexity leads us to conceive the tasks involved in the preservation, restoration, and reissue of twentieth-century music not as separate actions but as parts of a single process that perpetuates the life of its works.

NOTES

1. "C'est que la *diffusion* (qui s'impose, dès le départ, comme la mission même de radiotélévision, dont elle justifie l'existence) ne devient que progressivement une tout autre réalité : un *phénomène social*, désormais susceptible d'exercer sur le message une *action en retour*." Unless otherwise indicated, all translations are the authors'.

2. For a review of the contemporary work on the ontology of music in analytic philosophy, see Davies (2020).

3. To give audio research activities the status of an academic discipline, Stephan J. Cottrell (2010) suggested that this kind of work be called "phonomusicology." He states that are "a variety of articulations between recording technology, musical performance and creativity in the recording context, which provide potentially rich sources of data for phonomusicologists in relation to the way in which technology affects the final product" (9).

4. "Les développements de l'enregistrement sonore sont maintenant tels que nul spécialiste, semble-t-il, et *a fortiori* nul profane ne saurait sans outrecuidance prétendre parvenir à un recensement exhaustif des archives sonores du monde, d'autant que, simultanément celles-ci restent encore affaire de pionniers."

5. "Né un conservatore né un restauratore può pretendere tanto, appunto perché è una pretesa, un'indimostrabile pretesa quella di poter risalire ad un supposto aspetto originario di cui la sola testimonianza valida sarebbe l'opera allorché fu compiuta, ossia senza il trapasso nel tempo, ossia un'assurdità storica."

6. The idea of choosing a "best copy" stems from information theory, which has its basis in the transmission engineering and statistical genetics studies of Ronald Fisher, Galton Professor of Eugenics at University College London and editor of the *Annals of Eugenics.* For an in-depth historical analysis of the various theoretical components that have informed information theory, see Segal (2011).

7. The sociological approach is concerned with the characteristics of historical systems for the storage and distribution of sound; it aims to provide a historical reconstruction of the recording as it was heard in the past, with the goal of writing a history of listening habits. It answers the question: how was the published document perceived?

8. Above, we have taken up Battail's concept of regeneration as a way of reducing transmission errors in relation to a pattern. Here, we must further distinguish between regeneration and resynthesis, both of which are present in Pottier's work. The latter can only be understood as regeneration if we treat this process as a form of anti-historical re-mediation—that is, if we think of the code as disembodied from the system, medium, musical habitus, and sound production conditions (e.g., digital-to-analog converters) that created it.

9. (1) "réduite à 4 minutes, sans les parties centrales…. Cette version utilise trois claviers MIDI, un Kaoss Pad et un ordinateur (programme Max/MSP)"; (2) "reconstruction de la pièce en version 4 pistes en utilisant le programme Csound (V2a) et le programme Max/MSP (V2b)"; (3) "*Turenas Live* pour quatre percussionnistes et un dispositif temps réel"; (4) "*Turenas Live II*, avec reconnaissance de partition, pour quatre percussionists at un dispositive temps réel."

10. "d'archiver et de documenter la partie technologique de l'intégralité des pièces électroniques créées à l'Ircam, dans l'état technologique de la création ou de la dernière exécution."

11. "Das Vermögen der Phantasie ist die Gabe, im unendlich Kleinen zu interpolieren."

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